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An Evaluation of Activity in a Colonial Maya Cemetery Using Femoral Cross-Sectional Analysis

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AN EVALUATION OF ACTIVITY
IN A COLONIAL MAYA CEMETERY
USING FEMORAL CROSS-SECTIONAL ANALYSIS

by

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ABSTRACT

Cortical bone formation in the population of Tipu, a colonial visita site in Belize, was examined here to reveal factors of their activity and address the possibility of a status-based burial plan. To answer this question, this research examined the endosteal surface of the midshaft femur using digital imaging methods. The femora from 70 individuals were photographed and examined using the BoneJ plugin in ImageJ software. The cortical bone area was compared to additional variables, including sex, age, stature, pilastric index, and burial location. It was hypothesized that sex, age, and stature would correlate with cortical bone area similarly across the population, but that pilastric index and burial location would reveal distinct groups of individuals with differing activity.

The results show that sex is correlated strongly with cortical bone. Age also trends in the expected direction, but all other variables fail to demonstrate significance. Therefore, no indication of elites within the cemetery can be determined. This could indicate that femoral cortical bone area is an ineffective measure of activity levels among social groups, necessitating other methods to evaluate status at Tipu. These results may also show a changing cultural landscape for the Maya with the infusion of Catholic traditions. However, the activity differences for those of varying social status may be too nuanced to significantly affect cortical bone area. Further research is needed on this population using different evaluation criteria to determine if a burial plan exists.

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CHAPTER I – INTRODUCTION

The human body is an exhaustive record keeper. Throughout the continuous cycle of growth and change, biological evidence endures to document a lifetime of experience. Bioarchaeology resides at the intersection of biology and culture, with a goal of inferring cultural characteristics from skeletal remains on both individual and populational levels. It is a multidisciplinary approach that incorporates elements of human biology, archaeology, and cultural studies (Armelagos 2003, 27). With a systematic approach, many factors of activities, lifestyles, diseases, and nutrition can be determined. As part of a populational study, these individual analyses culminate to provide details about the culture at large, helping to supplement our understanding of past lifeways. However, it is important to account for the fact that there are limitations on the quantity and type of data that can be discerned from skeletal remains, especially given that older burials are less likely to be well preserved (Weiss-Krejci 2011). Despite these limitations, technological and methodological adaptations in the discipline have allowed for a robust collective of information to be garnered. Skeletal remains are an especially valuable resource for studies of the past because they offer an objective view of an individual's life separate from other forms of historical evidence. This poises bioarchaeology to infer aspects of cultural identity and lifestyle from biological data.

Much of this evidence about a person's life remains in the bones after death, and it can be used to interpret activity patterns for populations that can no longer tell their own stories. The intention for this research is to interpret skeletal evidence in a way that can help tell the story of the inhabitants of Tipu. This site was a post-contact Spanish mission church in Belize, and most of the remains are estimated to have been interred between 1568 and 1638 (Graham et al. 1989). Because of the shifting political climate of the time, this population experienced tumultuous cultural change, which was accompanied by significant changes in health status. Spanish presence in the Americas was associated with a high prevalence of disease, a decrease in access to resources, and an overall lower life expectancy for indigenous peoples (Stodder and Martin 1992, 60-1).

In addition to diminished health outcomes, European contact was associated with changes in daily activity for the Maya. Diminished access to food resources and the demands of the Spanish to work for tribute necessitated increased manufacture of both food and non-food products (Graham et al. 1989). The resultant physical consequences, however, have not been well-studied in populations of the time. This research explores those consequences at Tipu using patterns of cortical bone distribution. By examining this particular physical feature of the population, it can be inferred how activity was distributed among them. This provides a narrative of how contact affected the work they performed in relation to their position in society, including gender, social rank, and age.

Tipu provides a great study sample to evaluate Maya health and lifestyles during the time of contact, especially due to its relatively good preservation. Although the church was undoubtedly erected under the guidance of the oppressive Spanish Catholic colonizers, evidence suggests that all the individuals interred at the site are of indigenous Maya ancestry. Because of dental characteristics, including the ubiquitous presence of shovel-shaped incisors, it is believed that many of the individuals in the population are closely related, and no Spanish admixture is suspected (Jacobi 2000, 5-76). Other studies have assessed their health based on factors such as infectious disease, porotic hyperostosis, and trauma (Cohen et al. 1997).

However, the maintenance of cortical bone among the Tipu inhabitants has not been previously examined. An aspect of lifestyle for which this data can be informative is patterns of habitual physical activity, especially in terms of sex, age, and status markers that are understood through the study of biomechanics. Bone formation and structure is not strictly related to biomechanical factors; age, sex, hormonal levels, and diet can all contribute to a person's bone density and shape. However, it is known from studies evaluating change with subsistence strategies that habitual activity has a significant effect on the amount of cortical bone present (Noldner and Edgar 2013, 417). Long bone diaphyses in particular have been an area of interest in biomechanical studies, because they are the sites of attachment for many of the muscles associated with weight bearing activity and therefore endure much of the biomechanical stress put on the body.

Because of the consistent and significant biomechanical force they withstand, femora are commonly analyzed for markers of habitual activity (Agostini and Ross 2011; Holt and Whittey 2019; Miller et al. 2018; Stock and Macintosh 2016; Wescott and Cunningham 2006). In particular, the diaphyseal shape is an area of interest, as it indicates the planes along which the greatest and least forces are applied, respectively. This can be examined using either external methods that look at the periosteal surface of bones or internal methods that look at the endosteal surface (Cooper et al. 2007). To utilize endosteal methods, the diaphysis must be physically or digitally cross-sectioned. Evaluations of cross-sectional femoral properties have shown significant differences from individuals of different lifestyles and population groups. For example, females typically have thinner cortical bone than males, especially with increasing age. Femur diaphyses of pre-agricultural populations have a distinctly rounder shape than those of postagricultural individuals (Miller et al. 2018). Modern femoral samples have also been compared for ancestral differences (Wescott 2006). The ability to examine femora for these and other characteristics makes them a valuable structure for assessing characteristics of a population.

While the specific daily activities of the Tipu population are not well-documented historically, it is likely they had a similar lifestyle to some contemporaneous populations. On a given day, many of the activities performed in a colonial Maya population would have been related to subsistence. The post-contact diet would have likely been more carbohydrate-rich than prior time periods (Larsen and Ruff 2001, 113-114). This is a direct result of Spanish presence, because the colonizers took much of the desired goods and foods consumed by the Maya for themselves, which reduced the variety and quality of indigenous diets (Larsen et al. 1992, 30). A result of this is having to process more agricultural products to supplement their diets. Their physical movements would have likely included pushing, lifting, and carrying loads for short distances. These patterns, as in most populations, would vary by gender and age due to variability in expected activity levels by societal role (Larsen and Ruff 2001). Maya women were also likely sitting for more of the time in order to process maize and produce crafts, such as woven fabric. The individuals at Tipu also likely represented multiple echelons in society, which would influence the level of activity expected of them. Some have suggested that the burial plan at the site may be indicative of status (Cohen et al. 1994, Jacobi 2000), and the activity patterns should be reflected accordingly based on burial location.

Analysis was conducted on the bisected, proximal femora of 70 adult individuals from the Tipu site, measuring cortical bone area and midshaft anteroposterior and mediolateral diameters. With the biological and cultural factors affecting the population considered, the initial hypothesis was that the femoral cross-sectional geometry of the Tipu population was likely to show a significant level of sexual dimorphism, age-related cortical bone loss, and status-related differences in habitual activity level. Predictions included that those buried in the front portion of the church would be of the highest status, with those in the back being lower, and those outside of the church being of the lowest status. It was also predicted that this would be indicated primarily by mean cortical bone area, with those of higher status being required to perform less habitual work, and therefore having a lower mass of cortical bone in their femora.

This research is a significant contribution to the literature on Maya bioarchaeology because it utilizes an approach that has not been carried out on a similar population. Cross-sectional studies have largely focused on the role of agriculture and sexual dimorphism and have typically sampled indigenous populations from the United States and South America. No Maya populations from the same time period have been assessed on these criteria. Additionally, many studies are unable to use the methods that have been available in this study, which affords this work a unique perspective on the endosteal morphology of a post-contact Maya population. A study of this nature provides new information about the cultural dynamic of Belize after Spanish contact and the activities that would have been performed there.

In utilizing this methodology, this research has been able to provide meaningful contributions to the collective of information about culture and status distribution in the colonial Yucatan. This study provides a closer look at how work expectations were distributed among individuals at the Tipu site, and it contributes to the body of research about the morphology of sex differences in agricultural populations in the Americas. Lastly, this endeavor has contributed meaningful historical knowledge to what is known about the lifestyle and culture of the people at Tipu, providing the opportunity to tell a piece of their story.

CHAPTER II – LITERATURE REVIEW

Understanding past cultures begins with an examination of what they left behind. This can include human remains, which provide information about their lifestyle and daily activities. Because skeletal material often comprises the only biological evidence available with passage of time, it is crucial in evaluating the interplay between biology and culture. Cross-sectional analysis of long bones serves as a useful method for examining this interaction, as it provides insight into activity levels in a population. It is important to review how this method can be appropriately applied to discern lifestyle factors for a particular population. What follows will be an examination of the literature describing the cultural context of colonial Yucatán and the study population of Tipu. The biological framework for the methodology of cross-sectional evaluation of cortical bone and relevant prior research will also be explored.

Culture of Contact

The colonization of the Americas was an exceptionally significant historical event, leaving lasting impacts on populations the continent over. Mesoamerica in particular was largely overtaken by Spanish forces whose influence indelibly changed the culture and lifestyles of indigenous peoples. Contact had varying degrees of impact on indigenous populations, but historical accounts suggest that they all eventually came to be oppressed to some degree (Aufderheide 1992, 165). In their desire to proselytize Catholicism, the Spanish established numerous missions in the New World to overtake the existing political and trade networks and force natives into providing them with tribute in the form of labor and goods (Stodder and Martin 1992, 60). Because the Spanish took much of the goods and food for themselves, contact likely also reduced the variety and quality of indigenous diets (Larsen et al. 1992, 30). This caused an increase in the amount of physical labor required of indigenous populations as they struggled to meet tribute demands in addition to their nutritional needs (Graham 2011, 197; Larsen et al. 1992, 29; Stodder and Martin 1992, 60).

Compared with the Caribbean and parts of North America, Maya populations were not as decimated by the diseases brought by colonialism (Kashanipour 2012). Though there was a great deal of intermingling among settlements, disease likely did not spread as quickly in the population due to their lack of proximity to one another (Graham 2011). The Maya resistance to Spanish rule may have also limited the access of colonizers to much of the population for a time, mitigating some potential disease transfer (Kashanipour 2012, 42). However, Spanish rule was still pervasive in its impacts on indigenous health and nutrition, which at times was exacerbated by local environmental conditions.

The Yucatan peninsula suffered a drought for half of the seventeenth century, from the 1630s to the 1680s, and the subsequent two centuries were also punctuated with long periods of drought (Kashanipour 2012, 51-52). This was the cause of cyclical famines, which likely would have increased the amount of subsistence work necessary for survival. Combined with the demand of tribute for the Spanish, this hardship required a great deal more physical labor to produce a sufficient crop yield (Kashanipour 2012, 46). In order to meet these demands, the Maya, indigenous to the Yucatán, would have been working harder to produce food in poor crop-growing conditions and likely going without sufficient nutrition for themselves if they came up short (Kashanipour 2012). In addition to the nutritional upset, there were also epidemics that swept through the region as a result of contact. Because the indigenous populations had no innate immunity to new diseases brought from Europe like smallpox, measles, and influenza, these pathogens were able to spread rapidly and had devastating health impacts in the region. These epidemics additionally interrupted trade routes and limited the ability to cultivate crops, which caused the already limited food supply to dwindle. The Maya population fluctuated greatly after contact with the onset and waning of each of these health events (Kashanipour 2012, 50).

Spanish presence had a clear impact on death rates among the Maya, including increases in infant mortality and decreases in overall life expectancy during the Colonial period. In addition, warfare and violence among indigenous groups desperate for resources left populations more vulnerable to the negative health effects of colonization before the Spanish had even made contact (Stodder and Martin 1992, 61). Additional loss of life occurred as a result of direct conflict with the Spanish, who were responsible for killing many Maya warriors attempting to defend themselves and their homes from conquest (Graham 2011, 41).

As evidenced by the ubiquitous presence of Catholic mission sites, an integral part of the Spanish strategy in the New World was religious subjugation. The Maya were especially resistant to this initially; they did not want to assimilate to Catholicism or pay tribute to the Spanish (Kashanipour 2012, 42). However, the Catholic influence eventually dominated colonial culture, including medical practice and political organization (Guerra 1963, 148). Fearing Maya spiritual traditions would jeopardize the spread of Catholicism, the Spanish governance aimed to eliminate indigenous beliefs entirely, targeting traditional healing practices for persecution. Friars were assigned to colonial settlements across Mesoamerica to enforce Catholic rule and dampen any practice of traditional Maya rituals (Kashanipour 2012, 170). There were a limited number of friars, however, so they would typically travel circuitous routes to visit different mission sites periodically. Because of this, more remote mission settlements would often not have a friar present for long periods of time, which allowed them to retain some traditional Maya practices that otherwise may have been stifled (Graham 2011). Much of Maya culture during colonial times would have incorporated their traditional rituals with Spanish influences, however. In attempting to reconcile the changes in their world, the Maya often secretly used familiar practices to ground their new cultural identities with their established customs (Masson et al. 2021). There is no definitive consensus for what populations were like in the Americas prior to contact, but there is no doubt the presence of the Spanish changed daily life in some way for all Maya populations (Crosby 1992, 277-278).

The People of Tipu

The Tipu site is situated among mountainous terrain near the Macal River in western Belize (Figure 1). Dating to 1541-1707, this Spanish mission church site operated as a place of worship, community, and daily activity for the population there (Graham et al. 1989). An archaeological excavation of the site took place in the 1980s, and over 500 burials were recovered from a cemetery in and around the church building (Cohen et al. 1997). The human remains and artifacts recovered there have been examined extensively in the subsequent years in efforts to better understand the lifestyle of the people at Tipu and how contact may have impacted them (Cohen et al. 1997; Graham et al. 1989; Graham 2011).

Figure 1. Map of Belize indicating location of Tipu site

(Wikimedia Commons)

The daily activities at Tipu may have been similar to pre-contact Maya populations, because colonial rule was not as domineering inland due to their remote location and lack of prized natural resources for the Spanish to exploit (Graham 2011). While demands for tribute would have affected all Maya populations under colonial rule, archaeological evidence from Tipu suggests that they continued to produce the same crops and utilize the same faunal resources, with no apparent intensification of these practices at any point (Graham et al. 1989, 1255). This still does not preclude a change in workload, however, and any increase that did take place would have been different for males and females. Gendered work disparities have been observed in populations at all points of Maya history (Wanner et al. 2007, 261; Maggiano et al. 2008, 471). However, populations from as early as the Late Classic time period demonstrate that skeletal evidence of gendered work disparities was becoming less apparent over time (Wanner et al 2007, 262), so they would have likely decreased further by the time of Spanish contact. If paying tribute to the Spanish were a cause for an increase in the activity levels at Tipu, some sex differences would still be expected. Women would likely be more involved in planting and processing crops and traditional basket weaving practices, whereas men would participate more intensively in hauling harvests and faunal processing (Graham et al. 1989; Wanner at al. 2007).

A corequisite to changing workloads as Maya culture evolved was changing status, particularly for women, which may help explain the secular decrease in biological evidence for gendered work patterns. Evidence from Classic period Copán and Late Classic Altar de Sacrificios show an emerging pattern of status changes. In the earlier times, women would have had more access to power through their roles, but their ability to maintain high status began to wane (Ballinger 1999). Colonial presence likely precipitated the greatest loss of status for women in Maya society, as Spanish moral imperatives dictated that women were below men. By virtue of these imposed values, it is likely that Colonial Maya women like those at Tipu were not able to obtain prominent status in their society (Ballinger 1999).

The settlement at Tipu was the last in a series of mission sites out of Bacalar that stretched over much of central Belize. It was a smaller church than those at other sites on this circuit like Lamanai, likely because it was over 200 kilometers from Bacalar and seldomly visited by the Spanish missionaries due to the arduous journey required to get there (Graham 2011, 200). Tipu served as the site of interment for its residents, whose remains are located both within the walls of the church and throughout the surrounding grounds (Figure 2). Based on Catholic traditions of the time, those interred in the front are presumed individuals of higher status due to their proximity to the altar (Cohen et al. 1989; Noldner 2013; Saul 1982).

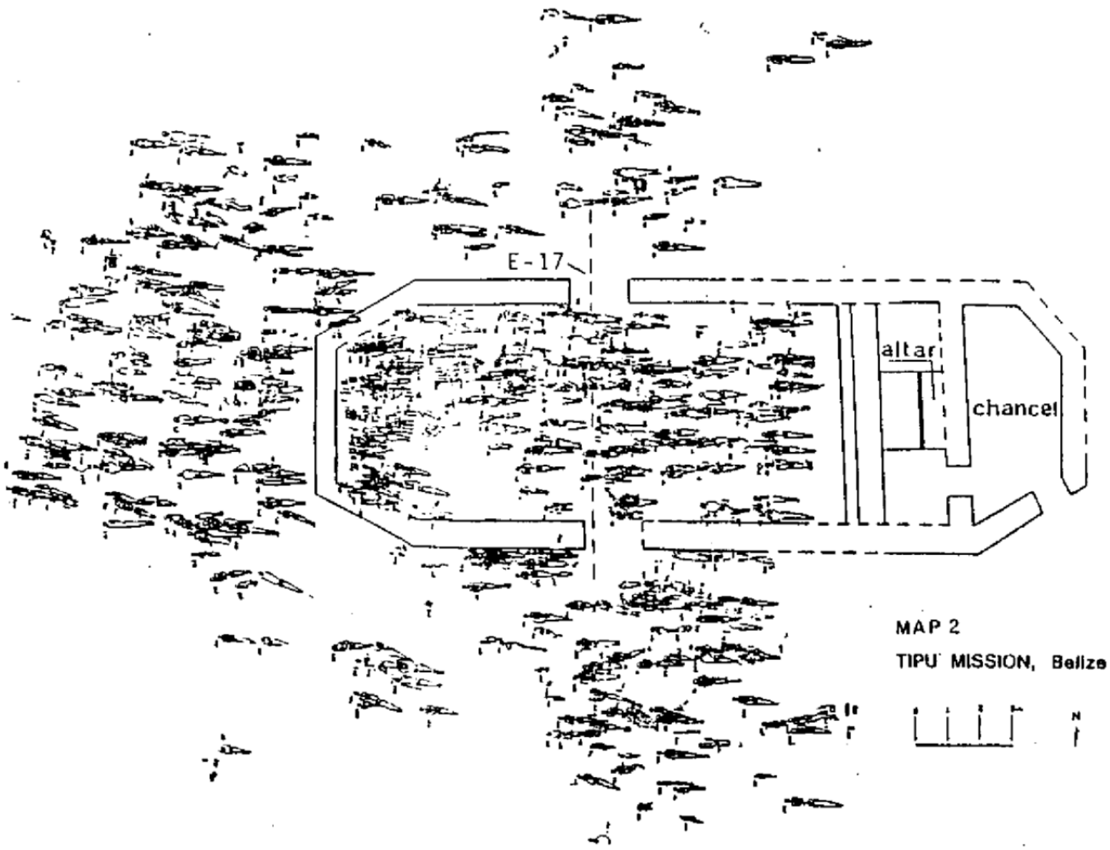


Figure 2. Map of burials in relation to the church at Tipu

(Cohen 1997)

It is known from the presence of the church at Tipu that the Catholic influence from the Spanish was present there. The site's burial plan, along with the artifact assemblage, suggest a blending of Catholic influences with traditional Maya cultural practice (Graham 2011). However, the location and context of the site, along with the apparent lack of permanent Spanish residents, suggests they were more autonomous than most Maya (Graham 2011). Additionally, the site is very remote and outside of most of the primary trade networks established by the Maya prior to contact, which the Spanish later used as a framework for their own trade routes. Therefore, the Tipuans likely were not watched as carefully by the Spanish, allowing them to sustain more of their pre-contact cultural practices than more closely scrutinized populations. The residents there would have evidently preferred it this way, as they reportedly drove the Spanish from their settlement and may have burned down a church in rebellion at one point (Graham 2011). Because of the lack of military presence and relative autonomy of the site, the Tipu settlement also served as a haven for refugees fleeing Spanish oppression. This lends credence to the idea that Tipu was uniquely situated to retain Maya traditions more freely than those under closer watch from the Spanish. Still, there is evidence in the burials and artifacts that some Spanish cultural traditions beyond those seen at the mission church leached into the Tipu way of life (Cohen et al. 1997).

The refugees present at Tipu likely came from areas where forced labor to produce tributes was more heavily imposed. This would cause their activity patterns to likely differ from those of lifelong Tipu residents if the latter were not forced to work as much to meet tribute demands. No research has yet determined from their remains who among the Tipu population was a refugee, making the prospect of examining their activity levels challenging (Jacobi 2000).

The later time period of Tipu compared with precontact Maya sites frequently studied might suggest that they would demonstrate a secular continuation in the trends observed through Classic Period populations, but the political dynamic might have forced their activity patterns to change course. The Postclassic Maya had already splintered off into smaller communities which were heavily reliant on trade (Graham et al. 1989). The Spanish taking political control would have impeded this practice from continuing during colonial times. So, with Tipu being under Spanish control, did this have the assumed effect on their labor practices and subsistence strategies? Did the new political reign impose a status hierarchy that is demonstrable through the site's burial practices?

The answers to these questions could ostensibly be revealed through analysis of Tipu's skeletal remains. However, Spanish occupation may have affected this population more subtly than other Maya groups. Tipu was resistant to Spanish rule, although the lack of Spanish remains at the site indicates they likely cooperated enough to keep from having a military presence imposed on them. Evidence from the site suggests that they maintained Catholic practices, likely of their own accord due to the diffusion of Spanish culture into Colonial lifeways (Graham et al. 1989). They were mostly left to their own devices, as evidenced by the fact that their subsistence practices remained mostly unchanged (Graham et al. 1989).

In terms of bioarchaeological data, the Tipu population provides a robust sample for elucidating how colonialism may have affected their health and lifestyle (Cohen et al. 1997). Various avenues of research have been utilized to evaluate how the remains from Tipu can be interpreted (Jacobi 2000; Noldner 2013; Cohen et al. 1997). However, there are as of yet unexplored lines of osteological evidence from the site that may serve to further understanding of the cultural dynamic between the Maya and the Spanish. Among these is cortical bone formation, which affords a perspective into the patterns of physical activity in the Tipu population, giving insight into their habitual movement and, thus, their culture.

Cortical Bone Maintenance in the Human Skeleton

The primary tenet of skeletal biomechanics is Wolff's Law, which states that there is a correlation between mechanical loading and bone formation (Bertram and Swartz 1991, 253). Cortical bone is the densest type of skeletal tissue. It is structured to maintain maximum load bearing capacity while not creating too much metabolic demand on the body. Its structural matrix is composed of hydroxyapatite crystals and collagen fibers. This combination of materials makes it at once rigid and flexible, allowing it to maintain structure and withstand the sustained force of supporting the body (Weerasooriva et al. 2016, 74). Part of the strength of bone lies in the organization of the matrix. The structure is hierarchical from the level of cells to tissues, with lamellae, the smallest unit of cortical bone encircling haversian canals, mimicking the cylindrical shape of cell-level osteons. In cortical bone, the varying orientation of these osteons gives it strength to accommodate mechanical loading (Weerasooriva et al. 2016, 74). Long bones endure the bulk of mechanical loading force, making them the most valuable part of skeletal anatomy in the study of biomechanics (Mantini et al. 2010, 102).

In response to mechanical force, the structure of bone is able to make changes to accommodate. Load bearing or trauma triggers the body to deposit or remove cortical bone where necessary. Sustained mechanical loading results in more bone being laid down at the site of strain to compensate. The point at which the body responds to force by beginning to deposit new bone tissue is called the strain threshold (Agostini and Ross 2011, 339). Once this threshold is reached and cortical bone is deposited in response to habitual physical activity, the shape of long bone diaphyses will begin to change. These variations in shape are adaptations so that the bone can reduce the stress caused by loading (Ruff and Hayes 1983, 373). By analyzing diaphyseal shape and robusticity, cross-sectional geometry can indicate how much force has been exerted on the bone and its directional distribution (Mantini et al. 2012, 102).

If the ratio of bone deposition on the anteroposterior axis is greater than that of the mediolateral axis, this results in a morphological effect called pilastring. This is caused by a disproportionate strain on the vastus muscles of the anterior thigh, which insert at the linea aspera (Holtby 1918, 373; Trinkhaus and Ruff 2012). However, an especially prominent linea aspera is not necessarily an indicator of pilastring, as it would have to be markedly more developed than the transverse diameter of the diaphysis. There is also no direct correlation between the length of the femur and the degree of pilastring (Holtby 1918, 372-374). In order to assess whether or not a femur has definitive pilastry, and thus has borne a greater deal of strain in the anteroposterior axis, the pilastric index must be calculated with diaphyseal measurements. The degree to which individuals may exhibit pilastring can be dependent upon sex and populational specificity, but it provides a helpful basis for comparison within a population of which individuals may have habitually performed the most “legwork” (Holtby 1918, 372-374; Trinkhaus and Ruff 2012).

Because the diaphysis is subject to depositional bone growth throughout a person’s lifetime, factors other than habitual physical activity can have an effect on its shape. These include genetics, age, sex, hormonal factors, nutritional status, and pathology (Agostini and Ross 2011, 339; Mansukoski and Sparacello 2018). In all individuals, growth and aging have an impact on cortical bone, but this varies by life stage and body composition. For females in particular, aging has a substantial impact on cortical bone density. Early in life, male puberty causes an increased deposition of bone where female puberty does not. This early discrepancy is never equalized, because female hormones caused an increased rate of resorption of cortical bone compared with males. This can lead to osteoporosis later in life, a pathology that disproportionately affects females (Seeman 2001).

During the periods when growth occurs at the fastest rate, such as early childhood and puberty, bones have the greatest elasticity. Formation can be hindered or augmented by nutritional status and sex hormones (Seeman 2001). It is during childhood and adolescence in particular when cross-sectional anatomy can be most indicative of mechanical stress because of its constant reformation (Saers et al. 2017, 133). However, given age, sex, and other factors that affect cortical bone density, the literature supports the idea that mechanical load has the greatest differential effect on individuals within the same demographic groups (Agostini and Ross 2011, 339). The habitual force of muscles acting on bone has the most significant impact on overall bone shape as well (Pomeroy et al. 2017, 57). The shape of lower limb bones especially has been demonstrated to strongly correlate with subsistence-related activities such as lifting and long-distance walking (Holt and Whittey 2019, 1).

Biological Factors of Bone Formation

The density of cortical bone has been linked to factors such as body mass, ancestry, mobility, and status in various populations (Agostini and Ross 2011; Pomeroy et al. 2018, Wescott 2006; Stock and Macintosh 2016; Noldner 2013). Agricultural activity in particular produces relatively strong bones, as it requires a substantial workload (Bridges 1989). Women in agricultural populations also typically have greater levels of activity when compared with men (Bridges 1989). This is especially correlated with the processing of maize, an integral crop in Mesoamerica (Graham et al. 1989). Age also correlates heavily with cortical bone mass, as the rate of resorption is greater than the rate of apposition in diaphyses in later adulthood. Those who had a greater bone mass to begin with, however, will lose it more slowly (Seeman 2001).

Mobility is a facet of activity that greatly affects the morphology of long bones in the leg (Stock and Macintosh 2016). Studies have consistently shown that populations with a lower degree of mobility will have less robust cortical bone in the femur and tibia in particular (Holt and Whittey 2019; Maggiano et al. 2018; Stock and Macintosh 2016; Wanner et al. 2007). One study examined how the femora of Neolithic populations changed with decreasing mobility patterns. The resulting data indicates a decrease in femoral rigidity over time, with the diaphyses becoming more circular as a result of decreased mobility in the more recent groups (Stock and Macintosh 2016). In addition to the degree of mobility, the terrain can also have an effect on long bone apposition. Holt and Whittey (2019) demonstrate that the diaphyseal shape of femora and tibiae is significantly different depending on the terrain traversed by the study populations. A temporal decrease in the anteroposterior and mediolateral diameters of long bones is also demonstrated, indicating that an overall secular decrease in skeletal robusticity was likely due to less travel post-agriculture (Holt and Whittey 2019).

An individual's role in a population can also have a direct impact on the factors that influence their cortical bone formation. The effect of status on long bone diaphyseal morphology can be manifested by both differential access to resources and unequal distribution of manual labor (Saers et al. 2017; Maggiano et al. 2008). This important facet of culture can be explored by comparing individuals of different social classes to observe how it affects their maintenance of cortical bone. In a Dutch pre-industrial population, lower limb cross-sections revealed that rural, and therefore lower status, individuals had a greater workload than those in a nearby urban center (Saers et al. 2017). Similar findings regarding status differences have been observed in Mesoamerican populations. At Xcambó, dating to the Classic Period between 250-700 AD, of Maya groups, those of higher social status were shown to have less rigidity in their humeri and femora, indicating a lighter workload than that of lower status individuals (Maggiano et al. 2008). Ballinger (1999) assessed Late Classic sites Copán and Altar de Sacrificios in comparison with Tipu and discovered that arm bone robusticity was more pronounced in the earlier populations. This change is asserted to be associated in part due to the changing nature of status in Colonial Maya life. This was especially true for women, whose status had begun to wane in the Postclassic period amid tensions between the male-dominated ruling class and the working class, which heavily depended on female labor (Ballinger 1999, 109-110). The status of women was diminished even further with the Spanish presence and the patriarchal ideologies of Catholicism. Additionally, craft specialization and religious leadership among the Maya had begun to increase into the Postclassic and Colonial periods. This social landscape caused a shift away from primarily hard physical labor for many individuals (Ballinger 1999, 93-158).

One common method to evaluate sexual dimorphism in workload distribution among populations is through cortical bone analysis. Such research has demonstrated a great deal about workload distribution among populations. Historically, populations in the Americas have been shown to exhibit sexual dimorphism to some degree (Larsen and Ruff 2001; Maggiano et al. 2008; Miller et al. 2018; Stock and Macintosh 2016; Wanner et al. 2007 Wescott 2008; Wescott and Cunningham 2006). Sex differences in long bone morphology can differ greatly by population, however, which is usually related to workload patterns associated with subsistence, such as processing maize or transporting items (Larsen and Ruff 2001; Wanner et al. 2007). In some populations as far back as the Neolithic, sexual dimorphism appeared to increase over time, which can potentially be attributed to the travel patterns associated with gendered roles in food acquisition (Stock and Macintosh 2016). Among Native Americans from the Great Plains, external diaphyseal measurements indicated that females showed the greatest morphological changes with shifting subsistence patterns (Wescott 2008). They became more robust, and therefore less dimorphic from the already robust males, with an increased workload (Wescott and Cunningham 2006). Dimorphic bone characteristics have been observed in more recent Colonial-era populations, including Tipu, which have shown a marginal secular decrease in sexual dimorphism attributed to greater similarity in the subsistence tasks of men and women (Larsen and Ruff 2001; Ballinger 1999; Noldner 2013; Wescott 2008).

Populational characteristics unrelated to cultural labor patterns also influence cross-sectional properties. Ancestry has also been demonstrated as having a strong effect on cross-sectional shape of the femur in particular. When compared based on diaphyseal shape, Native Americans can be easily distinguished from modern American black and white individuals. Native Americans have much more oval-shaped cross-sectional profiles, compared with the more rounded shape of the latter groups (Wescott and

Srikanta 2008). This method is reliable enough to be recognized as a valid form of differential identification in forensic investigation; however, its applicability is limited for historical populational study (Wescott 2006; Wescott and Srikanta 2008). Because of the great degree of populational specificity for femoral morphology, it is important to know the scope of applicability for research of this nature.

Lifetime maintenance of cortical bone is another important consideration for studies of cross-sectional geometry. A study using computed tomography scans on living individuals evaluated how cortical bone porosity changes with age. Male and female participants of varying age groups were studied, and females were shown to have the greatest change in porosity with age. The most significant increase in cortical porosity in the female group occurred at around age fifty, which coincides with the onset of menopause and decrease in estrogen levels (Cooper et al. 2007; Singh 2002).

Body mass is an additional influence on patterns of cortical bone maintenance. In studies assessing cross-sectional morphology, researchers have often stated that it is important to correct for body mass, citing that it might otherwise skew the data (Larsen and Ruff 2001; Ruff and Hayes 1983). Those with lower body weight have a greater degree of porosity and larger medullary canals compared with higher body weight individuals (Cooper et al. 2007). However, more recent studies have indicated that body weight does not have a significant effect on femoral cross-sectional shape. In a 2011 study, obese body weight was shown to influence mediolateral size, but not shape. In essence, the diaphysis will retain its overall shape, but will increase in diameter along the mediolateral plane through apposition of bone on the periosteal aspect (Agostini and Ross

2011). An additional study assessed whether cross-sectional shape could be used to predict body mass, and no correlation was found (Pomeroy et al. 2017).

Cortical Bone Measurement

Given that mechanical loading comprises the greatest impact on diaphyseal cortical bone formation, visualizing the shape of a long bone diaphysis is a valuable way to gain insight into activity patterns for individuals and populations (Maggiano et al. 2008; Ruff and Hayes 1983; Stock and Macintosh 2016; Wescott 2008). Cortical bone morphology can be studied using any of several methods, most of which can be applied to any load-bearing bone in the body. Long bones are typically used, and many studies have been conducted using the humerus, femur, and tibia or any combination thereof. However, the femur is most often included in these studies because femoral robusticity in particular is a promising indicator for a general trend in physical activity (Bridges 1989). Whichever bone is utilized, the best method for a particular investigation depends on the sample being studied, the availability of technology, and whether destructive techniques are permitted.

To visualize cross-sectional geometry of long bones, the methods available can be divided into essentially two categories: periosteal and endosteal. Periosteal studies are non-invasive, as they use external measurements or imaging techniques to estimate the shape of the endosteal, or inside, bone surface without cutting into the bone. These can include two-dimensional methods like bone measurements and surface imaging. Three-dimensional methods such as 3D scans and computed tomography (CT) are also available. In studies of living people, CT scans are typically used. These scans are highly accurate and can be used to visualize small details, such as porosity in cortical bone

(Cooper et al. 2017). However, CT scans can be prohibitively expensive and time consuming, and they are not typically necessary to examine skeletal remains.

External measurements have been used frequently in studies of long bones because they are a non-destructive technique and do not require the use of sophisticated or specialized tools (Holt and Whittey 2019; Wescott 2008). External measurements are typically taken along the shaft of the bone at multiple points (Agostini and Ross 2011; Trinkhaus and Ruff 2012). In a study utilizing external measuring techniques, ten different measurements were taken at both midshaft and the subtrochanteric portion of the femur (Wescott 2008). These included mediolateral diameter and anteroposterior diameter. Using these external measurements, the cross-sectional geometry of the endosteal femur was estimated through calculations of the second moment of area and subperiosteal area with existing formulae (Wescott 2008). These types of measurements have been evaluated for their accuracy, and they do not hold up to three-dimensional analysis, as there is a great deal of interobserver error (Noldner and Edgar 2013).

There is also no reliable way to visualize the cortical bone thickness or medullary canal shape with external measurements alone (Wescott 2008). Three-dimensional surface scanning is a more accurate method because it has a lower rate of interobserver error (Noldner and Edgar 2013). This method has also been used to analyze the development of muscle attachment sites in biomechanical research (Noldner 2013). Overall, the external measurements that are accessible are limited in the accuracy of information they can provide about mechanical loading properties of long bones (Ruff and Hayes 1983, 359). They do, however, prove beneficial for use on collections where invasive and destructive methods are not possible.

One invasive method that has been used to examine cross-sectional geometry is the application of analytical software on two-dimensional images. In a study by Ruff and Hayes (1983), femora and tibiae were cross-sectioned at multiple locations along the diaphysis, and images were taken of the endosteal area. These images were processed using the computer program SLICE to measure geometric properties to determine the axes of bone that endured the greatest strain. The researchers used a stylus to manually trace the cortical bone area on the endosteal images and calculated cortical bone area, medullary area, and subperiosteal area. This study aimed to assess this methodology, and it was determined that two-dimensional endosteal analysis is an accurate and cost-effective technique for the study of cross-sectional geometry, when physical cross-sectioning is permitted (Ruff and Hayes 1983).

The way cultural factors can affect cortical bone robusticity has been evaluated using methods that range in accessibility and accuracy, leaving researchers with various options to cater to the limitations posed by different study collections (Davies et al. 2012; Noldner and Edgar 2013). The evaluation of cortical bone robusticity is invaluable for interpreting how habitual activity causes force to act on the shape and size of long bones (Bertram and Swartz 1991; Mantini et al. 2012). It has been demonstrated by research in indigenous American populations that cultural factors such as subsistence strategy, mobility, and status can affect the morphology of long bones across populations (Bridges 1989; Larsen and Ruff 2001; Noldner 2013; Stock and Macintosh 2016). Research has demonstrated that long bone robusticity, and therefore workload, has decreased significantly over time in New World populations due to a secular shift away from long-distance walking with agricultural intensification (Larsen and Ruff 2001). This same pattern has been elucidated in Mesoamerican populations from the Early Classic to Late Classic Periods, with the most pronounced decreases being among male individuals (Ballinger 1999; Maggiano et al. 2008; Saul 1972; Wanner et al. 2007). These findings collectively illustrate a decrease in the mobility of Maya populations over time, which has significant implications for more recent populations like Tipu.

However, research on this type of evidence has the caveat of being very population-specific (Larsen and Ruff 2001; Miller et al. 2018; Wescott 2006; Wescott and Cunningham 2008; Wescott and Srikanta 2008). With the variation in labor patterns and status by cultural group, applying new methods to a particular study population will always be valuable to garner more insight as to how culture specifically affected their workload and thus their bone density (Larsen and Ruff 2001). Because the Tipu population has not been evaluated for status or the cultural impacts of colonialism using cross-sectional methods on the femur, this method can provide new understanding of their activities and overall way of life.

Activity Patterns of Tipu

Because of its positioning as a remote, primarily self-sufficient site, Tipu would be expected to contain individuals who demonstrate a great deal of subsistence and travel-related activity. Additionally, their cultural position of being subject to the forces of colonialism would indicate likely differences in the distribution of work among individuals of different status. Cortical bone distribution among the population can help to show more about how these forces may have played out. Noldner (2013) explored the possible impacts of status in the Tipu population for her dissertation research by comparing enthesis development and cross-sectional geometry in upper and lower limb bones. A sample of 24 female and 33 male individuals between the ages of 20 and 50 were chosen from Tipu based on enthesis preservation. This sample was compared with elites and non-elites from precolonial contexts. The resultant data showed little difference between elites and non-elites (Noldner 2013). Noldner also compared subgroups within the Tipu population. Assuming those inside the church were of higher status, she compared them with those outside of the church and found no significant difference. There are differences in the data from this research that approach statistical significance, indicating that lower-status individuals may have been more mobile. Among the population, a homogeneity of body size was observed between sexes inside and outside of the church. There was also little notable variation in cross-sectional properties by age and sex groups, though males were predictably more robust. Among males and females, cross-sectional femoral shape was homogenous for all burial locations. However, certain burial clusters from both inside and outside were more robust than others. Overall, males showed much more variation than females, but the combined data did not strongly indicate status based on burial location at the site (Noldner 2013).

Ballinger (1999) explored status in Maya populations at Tipu, Copán, and Altar de Sacrificios, reporting that the greatest indicator of status at those sites was burial treatment in terms of the effort put into an individual’s interment and the grave goods present. Biological evidence suggested that those at Tipu had greater clavicle robusticity than the precontact sites, indicating a greater degree of upper body activity. Males in the population also exhibited stronger development of the pectoralis major. However, overall upper limb robusticity was similar for the three groups, indicating that their activity patterns had likely been mostly the same through precolonial and historic times

(Ballinger 1999). Because there is little material evidence of differential burial practice at Tipu, biological evidence is necessary to affirm any assumptions about how status may be represented at the site. While there were biological differences between individuals of different status at Copán and Altar de Sacrificios (Ballinger 1999), the changing social environment through the time of Tipu may have altered the way status may be recognized using the bioarchaeological evidence.

A reliable and effective method of evaluating habitual activity that has yet to be applied to the Tipu population is the analysis of cross-sectional bone robusticity (Davies et al. 2012). This method can help in providing insight into what a habitual workload looked like for the residents of Tipu as well as how the work expectations varied for different demographics in the population (Mantini et al. 2010; Miller et al. 2018; Ruff and Hayes 1983; Wescott and Cunningham 2006). Distinguishing among individuals as to who had a greater lifelong pattern of activity may help to demonstrate which individuals in the Tipu population were most affected by the presence of the Spanish. Additionally, an examination of the endosteal surface of Tipu's cross-sectioned femurs would potentially elucidate activity patterns in the population that have gone undetected with previous analytical methods. There is potential for a study of this nature to change the posture of Noldner's (2013) dissertation results by bolstering the significance of her hypothesis that status relates to burial location. Alternatively, endosteal data could denote the opposite by proving no correlation between activity level and burial location, effectively eliminating the possibility that the site's burial plan is based on social position. In either case, a further examination of the activity patterns will help aid in our further understanding of life and culture at Tipu.

CHAPTER III - METHODS AND MATERIALS

The purpose of this chapter is to describe selection of the individuals of Tipu whose femora were included in this research. Data collection and analysis will also be described to illustrate how this investigation was conducted.

Sample Selection

The Tipu population currently in curation at the University of Southern Mississippi consists of over 500 burials. For the purposes of this research, only adult individuals with well-preserved, previously cross-sectioned femora were chosen for the sample. Juveniles were omitted from the sample because of the high variability of cortical bone density during the periods of rapid development prior to adulthood (Seeman 2001). Preservation was considered in sample selection because a certain level of periosteal integrity is necessary for cortical bone assessment. Those with no prior femoral cross-sectioning had to be omitted because those destructive methods are no longer sanctioned for research on indigenous populations. The existing cross-sections were conducted in the 1980s using a band saw, before the adoption of these standards, when it was a standard practice for research of this kind (Ruff and Hayes 1983; van Gerven et al. 1969). No known research was produced from the resulting data. For most individuals in the collection, one femur is cross-sectioned one centimeter distal to midshaft. There is also no distinguishable pattern of a preference for the left or right femora, except in some cases where one femur was already broken or poorly preserved. Therefore, there is no indication that the cross-sections were initially made with any intention of exploring side-dependent research topics.

Ultimately, 70 individuals meeting the research criteria were selected from the Tipu collection based on their suitability for this study. Table 1 depicts the demographic composition and burial locations of the study sample as indicated in the records on file. The mean age range was determined for each by calculating the mean for the lower age estimates and higher age estimates of the sample individuals, respectively. These ranges, which were acquired from laboratory records, were recorded by previous researchers. In order to determine the age estimates, multiple skeletal elements were examined for each individual, varying in what was available for examination based on preservation and completeness of the skeleton. The estimates for age range given for different elements can vary, so they must be compiled to get the most accurate estimate. Unfortunately pubic symphysis morphology, the most accurate method of age estimation in adults, could not be used due to poor preservation of that element. However, another that was able to be applied in most individuals was cranial suture closure, with more closure indicating an older individual. The auricular surface of the sacroiliac joint was also used for age estimation, as its texture changes predictably with age due to walking. Those with a billowy surface are younger, and that texture tends to smooth out with age (Buikstra and Ubelaker 1994).

The sex for each individual was also taken from the records documented by previous researchers. This element of the biological profile is also ascertained using analyses of multiple skeletal elements. The skull contains many of these elements, with females generally being more gracile and males generally being more robust. The best skeletal indicator of sex, however, is the pelvis. Females tend to have a wider pelvic profile to accommodate childbirth, which includes a more open greater sciatic notch and a broader subpubic angle, which is derived from a longer pubic ramus (Buikstra and Ubelaker 1994).

The final portion of the data collected from records was the burial locations. These were recorded by the research team that excavated the Tipu site. The delineation between inside and outside of the church was obvious given that remnants of the church walls were still intact. However, the division between the front and back portions inside of the church was determined using E17 as an arbitrary marker to split the nave into east-west halves with the eastern half being closer to the altar (Cohen et al. 1989).

Table 1 *Demographic composition and burial locations of analyzed sample*

	Male	**Female**	**Total**
N	40	30	70
Mean Age Range	23.2-31.4	23.46-30.83	23.33-31.12
Burial Location (N):			
Inside Back	16	8	24
Inside Front	8	8	16
Outside	16	14	30

Data Collection

Where possible, endosteal methods are preferred for cortical bone assessment, because they allow for visualizing the internal bone surface directly. These methods have traditionally required that the diaphysis of the bone be physically cross sectioned with power tools. For the purposes of this study, direct endosteal observation was the method chosen, because the femora utilized had already been cross sectioned by previous researchers. In order to analyze the cortical bone digitally, part of the data collected from each individual included a photograph of the endosteal surface along with a series of measurements as described below.

For each individual, both the proximal and distal portions of the bisected femur were used in order to measure the maximum length of the femora. This measurement was used to calculate stature for each individual using the stature formulae developed by del Angel and Cisneros (2004):

Males – stature = 63.89 + 2.262 (femur length)

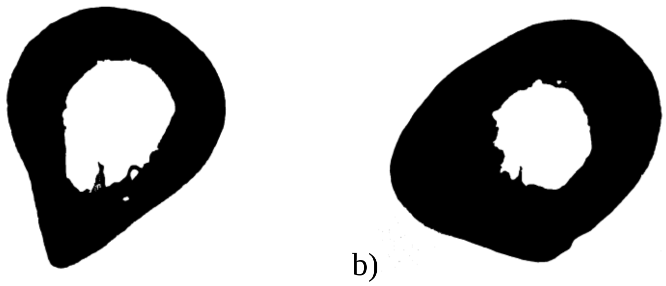
Females – stature = 47.25 + 2.588 (femur length)

The circumference of each femur was taken at midshaft, the site of the cross-sectioning, using a flexible measuring tape.

Two measurements of diameter were taken at midshaft on the proximal portion of the bone. The anteroposterior diameter was taken at the widest part of the bone, where the highest point of the linea aspera lies. The mediolateral diameter was taken perpendicularly to the previous measurement (Buikstra and Ubelaker 1994). These two midshaft dimensions were used to calculate the pilastric index of each individual using the following formula:

pilastric index = (anteroposterior diameter x 100)/ mediolateral diameter

Pilastrated femurs have a linea aspera which is disproportionately raised in comparison with the transverse dimensions. If a bone is pilastrated, the formula will produce an index of greater than 116 (Holtby 1918, 372-374), although this measurement occurs along a continuum. The figure below shows and example of two femora with high and low scores for pilastric index, respectively.



a) b)

Figure 3. Femora with pilastric indices of 129.6 (a) and 83.1 (b)

In addition to this series of measurements, a photograph was taken of the endosteal surface of each cross-sectioned proximal femur. All photographs were taken using a Pentax K-r DSLR camera with a DA 18-55m lens. A cardboard box lined in felt was used to support each bone and provide a contrasting background. A metric scale adhered to the front surface of the box was included in the frame of each picture, as well as a label with the burial number for each bone. An example of one of the photos is shown in Figure 4.

Figure 4. Photograph of the endosteal surface of cross-sectioned femoral midshaft, proximal surface

Data Analysis

In order to determine the cortical bone area of each femur, the raw .jpg images were each processed using the computer program ImageJ and its plugin BoneJ. First, the image was loaded into the program and a global scale was set. To do this, straight, one-centimeter line was drawn on the scale in the photo. Then the function analyze → set scale was used and calibrated with the known dimension of 10 millimeters for the line, which applies to the entire image while it is in the program. Then, each image was cropped to show only the bone, and any light-colored interference in the background was deleted using the tracing tool. For some bones, additional areas inside the medullary cavity had to be traced and blacked out to prevent the dirt inside from interfering with the analysis.

Once an image was cropped and areas of possible interference were omitted, the function image → adjust → color threshold was used to change the image type to YUV, or composite analog signals, adjusting the slide bar thresholds if necessary to make the image crisper. This resulted in a high-contrast black and white image, with the bone area appearing black and the background appearing white, as it appears in Figure 5.

a)  b) 

Figure 5. Original photograph of femur (a) and YUV image in ImageJ (b)

Once the image was converted to this high contrast version, it was converted to a binary, 8-bit image and saved as a tif file. Then the BoneJ plugin for ImageJ was used to acquire the cortical bone area with the function plugins → BoneJ → fraction → area/volume fraction. Using the scale previously set, this function populates area measurements for the entire image and for only the white portion of the image, including the background and medullary cavity. For most of the images, some tracing was done by hand to eliminate interference from dirt inside the medullary cavity. The area of the white portion was subtracted from the total image area to acquire the area of the black portion, or the cortical bone, in square millimeters. This entire process was performed thrice for each image, and the average of these three cortical bone area measurements was used for the final data analysis.

One alternative method to the BoneJ plugin was tested in ImageJ to determine cortical bone area. After the high contrast image was created, the automatic selection tool was used to outline both the subperiosteal area and medullary area, subtracting the latter from the former to acquire the cortical bone area. While this method worked for some of the images in the sample, those with a high degree of medullary porosity proved to make this method unreliable, so the results were eliminated from the final sample. An example of this interference is demonstrated in Figure 6 below, with the yellow outlines being those that the ImageJ program automatically detected.

Figure 6. Image demonstrating issues with ImageJ auto selection tool method

Statistical Analysis

To explore the relationships between the variables in this study, one-way ANOVA testing was conducted in Excel. Males and females were first split into two different groups and their cortical bone area measurements were tested to see if there were a significant difference between them, as might be expected. For all subsequent statistical tests, males and females were analyzed separately to account for their inherent differences in cortical bone area. Within each of these two groups, further one-way ANOVA tests were conducted to determine any significant relationships between variables.

The comparisons performed were:

- Cortical area inside vs. outside
- Cortical area inside front vs. inside back vs. outside
- Cortical area vs. stature (3 groups for each sex)
- Cortical area vs. age (3 groups for each sex)

- Cortical area vs. pilastric index (3 groups for each sex)
- Stature inside front vs. inside back vs. outside

The relationship between cortical bone area and burial location in the cemetery is the primary focus of this research, so it was evaluated in two ways. First, the sample groups were broken down to those inside and outside of the church and tested for a correlation. Additional testing was performed after splitting the inside group in two for the front and back of the church. For stature, the sex groups were each divided into three categories of equal range based on the mean stature of that sample group. For females, the three stature groups were 137-144, 144.1-149, and 149.1-155 centimeters in stature. For males, the groups were 150-156, 156.1-162, and 162.1-171 centimeters in stature. To test age against cortical bone area, the lowest age in the estimated range for each individual was used to divide males and females each into three age groups. For females, age groups consisted of 16-20, 21-29, and 30-40; the male age groups were 18-20, 21-29, and 30-35. The final variable tested against cortical bone area was pilastric index. The pilastric index for each individual in the sample was calculated using anteroposterior and mediolateral measurements with Holtby's (1918) formula. The males and females were each again separated into three groups of equal range based on the overall range of their pilastric indices. The female groupings were 83-93, 93.1-103, and 103.1-113, with male groups consisting of the ranges 90-103, 103.1-116, and 116.1-127. The only individuals in the sample that had definitive pilastry (Holtby 1918) were the three males in the latter group. The final ANOVA calculation was an evaluation of how stature relates to burial location at Tipu. The male and female groups were each split again into three categories of burial location in relation to the church: inside front, inside back, and outside. The final calculation performed was standard error of the mean for the cortical bone area in the entire sample.

The results of the data collection and analysis will be detailed in the following chapter.

CHAPTER IV – RESULTS & DISCUSSION

The objective of this research was to determine whether a correlation can be discerned between status and burial location in the Tipu cemetery using endosteal examination of femoral cortical bone. The initial testing investigated hypotheses about the trends in different demographics of the population. Males and younger individuals were presumed to display a greater degree of cortical bone development than females and older individuals, respectively. It was also predicted that stature and pilastric index scores would positively correlate with the area of cortical bone observed. The primary hypothesis was that this methodology would reveal a strong correlation indicating that those with greater femoral cortical bone area were buried further from the preferential location of the altar at the front of the church. This is based on the assumption that those of lower social status would be expected to have a higher degree of cortical bone area due to a more substantial workload. Therefore, those individuals closest to the altar, if of a higher status, would have a lesser degree of cortical bone development.

Sex

The first analysis conducted was to evaluate whether males and females in the sample varied greatly in their observed cortical bone area, as a degree of sexual dimorphism consistent with what is observed in other historical groups was expected in this population. For this research, the confidence level is 95%, so results are only considered significant if the p-value is less than .05. The results of the first test, shown in Table 2, indicate a very strong correlation between sex and cortical bone area. Females in the sample had an average of 18.64% less cortical bone than males. Because of this strong relationship, subsequent analyses were performed on each sex group separately.

Table 2 *Cortical bone area correlations between males and females*

Groups	N	Sum	Average	Variance	
Males	40	16755.418	418.885	2501.018	
Females	30	10225.082	340.836	1960.241	
Source of Variation	Sum of Squares	df	Mean Square	F	P-value
Between Groups	104429.25	1	104429.25	45.996	3.495E-09
Within Groups	154386.698	68	2270.393		
Total	258815.948	69			

Discussion

The significant difference between sexes in this data aligns well with expectations, as human populations typically exhibit a degree of sexual dimorphism. As observed here, males are generally of a larger size, with more muscle development and robusticity to their features. This is due to innate biological mechanisms primarily controlled by the endocrine system (Seeman 2001). Even in the Tipu population, which shows minimal sexual dimorphism in cross-sectional shape, these mechanisms caused significant sexual dimorphism in robusticity of muscle attachments (Noldner 2013).

While the biological contributors can reasonably account for the body size differences in males and females at Tipu, cultural factors likely also played a part. This is especially true for the formation of cortical bone as a response to mechanical stress. Differential workloads or occupations between the sexes are likely to have affected how their bones compensated for physical labor. Agricultural populations especially have consistently been observed to have sexually dimorphic cortical bone development, especially due to the greater degree of labor taken on by women to produce crops. This type of work mostly involved labor involving the arms while men’s work often involved transporting heavy materials, thereby causing a differential where women had greater arm development and men greater leg development (Larsen and Ruff 2001; Maggiano et al. 2008; Miller et al. 2018; Stock and Macintosh 2016; Wanner et al. 2007 Wescott 2008; Wescott and Cunningham 2006). This aligns well with what is known about work patterns at Tipu and the findings here.

Additionally, the sex differences in femoral cortical bone in the Tipu population coincide well with the historical context of colonialism. The differences observed are significant but not substantial, which coincides with a decrease in sexually dimorphic work patterns among many colonial populations in which the work done by all adults became more similar (Ballinger 1999; Larsen and Ruff 2001; Noldner 2013; Wescott 2008). This element of the sexual differential in cortical development likely relates to tribute work. Because the Spanish forced the Maya to pay tribute in both food and goods, the whole population would have had to increase their workload, with males and females likely taking up many similar tasks (Graham et al. 1989). This labor increase may have caused greater cortical bone development, but it would have affected both males and females. However, the biological factors that make males more robust on average still had their effect, thus making the two sexes at Tipu differ from one another in their cortical bone area.

Age

In addition to sex, the age of an individual is expected to show a strong correlation with cortical bone area. This is especially true of females, whose hormonal changes throughout life cause a much greater degree of age-related cortical bone loss than males (Seeman 2001). First, the females of the sample were examined to determine if this phenomenon can be observed in the Tipu population based on their femora. Subsequently, males were examined to see if their age corresponded to a loss in cortical bone, despite that this would not be expected to be as substantial as in females.

Females

Females in the sample were analyzed to see if their age corresponded to cortical bone area as predicted (Table 3). The lower limit of the age estimate for each individual was used to categorize them into the three groups for comparison. Age did not significantly correlate with cortical bone area in the females studied, and it in fact indicates an even weaker relationship than with other variables tested. Despite this, the results still trended in the expected direction, with the older individuals having less cortical bone on average than the younger groups. However, the age groups in this study sample are all relatively young and there is a relatively small number of individuals being studied, so age-related bone loss would not be expected to have a large effect on the sample. This could explain the lack of a significant correlation.

Table 3 *Correlation between age and cortical bone area, females*

Groups	N	Sum	Average	Variance	
16-20	13	4326.275	332.79	1702.153	
21-29	12	4281.294	356.775	2060.832	
30-40	5	1617.513	323.503	2089.96	
Source of Variation	Sum of Squares	df	Mean Square	F	P-value
Between Groups	5392.178	2	2696.089	1.415	0.26
Within Groups	51454.822	27	1905.734		
Total	56847	29			

Males

Age was then compared against cortical bone area in the male portion of the sample to determine if the two variables correlate, with results detailed on Table 4. Like the females, males were split into three groups and categorized based on the lowest estimate in their possible age range. With another very high p-value on this test, it was clear there was no significant relationship between age and cortical bone development in this sample group. Compared with the females, there was very little difference in mean cortical bone area between the middle and oldest groups. This aligned with what was expected, as males do not experience the same age-related bone loss as females and the sample is relatively young.

Table 4 *Correlation between age and cortical bone area, males*

Groups	N	Sum	Average	Variance	
18-20	21	8700.677	414.318	3458.114	
21-29	10	4237.042	423.704	870.525	
30-35	9	3817.699	424.189	2452.408	
Source of Variation	Sum of Squares	df	Mean Square	F	P-value
Between Groups	923.434	2	461.717	0.177	0.839
Within Groups	96616.264	37	2611.25		
Total	97539.698	39			

Discussion

Despite a lack of statistical significance, the relationship between age and cortical bone area in the Tipu population was still apparent. Even with a relatively small sample, which likely accounts for the statistical results, a trend was still readily observable with age. This was bolstered by the fact that the results differ by sex, which would be expected due to the fact that females lose significantly more cortical bone as they age than males do (Cooper et al. 2007). Also, the sample used here leaned quite young, ranging from teens into the forties. The hormone changes of menopause are the primary culprit for loss of cortical bone density in humans (Seeman 2001), but most of the females in this sample were well under the average age for its onset, even considering that historically menopause happened earlier on average than it does in modern populations (Singh et al. 2002). This would definitely contribute to the female group's lack of a significant loss of bone density, even in the oldest group. However, these results did still suggest that some degree of age-related loss occurred in females when compared to males, who did not show any decrease in average cortical bone area from the middle to oldest group. The degree of cortical bone loss for older females in the sample was very much evident, though not enough to make the results statistically significant.

These results aligned well with what was expected in terms of age-related cortical bone loss as observed in other indigenous American populations. The loss of cortical bone in the femur begins in middle age and is greatest in females aged 41-60 years old (Ericksen 1976; Feik et al. 2000). In older age, males will lose cortical bone density at the same rate as females, eventually tapering off for both sexes late in life (Feik et al. 2000). While the age range of this Tipu sample would preclude the observation of this age-related change, there was a clear decrease in female cortical bone area in the upper age limit of the sample. This observation was consistent with the beginning stages of significant bone loss accompanied by middle age as observed in other populations (Ericksen 1976; Feik et al. 2000).

Stature

The Tipu population exhibited expected values for stature in a Maya population of the time, with females being shorter on average and males taller (Cohen et al. 1994). It was predicted that the sexes would respectively display some degree of greater cortical bone area for the individuals with greater stature. This was based on the assumption that stature corresponds with the length of long bones (Agostini and Ross 2011), and larger femora would have a greater degree of cortical bone density for structural stability. Those with larger stature also typically carry more body weight, and this weight applies force to load-bearing bones that causes them to increase in robusticity to support the force of compression (Bertram et al. 1991). However, given the sample size and the overall small stature of a population of this nature, a strong correlation was not expected.

Females

Females were the first to be examined for a possible correlation between stature and cortical bone area (Table 5). This test yielded no statistically significant correlation; however, it did approach significance much more than tests of some other variables in this study, indicating that there was a potentially notable relationship between stature and cortical bone area. This was also observable in the trend of the mean values for cortical area, which showed a corresponding increase as the three groups increased in stature.

Table 5 *Correlation between stature and cortical bone area, females*

Groups	N	Sum	Average	Variance	
137-144 cm	10	3186.264	318.626	2849.539	
144.1-149 cm	10	3494.725	349.473	1166.665	
149.1-155 cm	10	3544.093	354.409	1464.474	
Source of Variation	Sum of Squares	df	Mean Square	F	P-value
Between Groups	7520.899	2	3760.45	2.058	0.147
Within Groups	49326.101	27	1826.893		
Total	56847	29			

Males

Stature was next evaluated against cortical bone area for the male portion of the sample (Table 6). This test yielded a relatively large p-value, indicating a definitive lack of correlation between these two factors. Statistically, stature and cortical bone area could not be associated as having any impact on one another for the males in the study sample. Still, the trend observed here was as would be expected, with the mean cortical bone area increasing with taller stature, as was observed with the female group.

Table 6 *Correlation between stature and cortical bone area, males*

Groups	N	Sum	Average	Variance	
150-156 cm	9	3761.644	417.96	4368.14	
156.1-162 cm	25	10349.712	413.988	1699.416	
162.1- 171 cm	6	2644.062	440.677	3670.433	
Source of Variation	Sum of Squares	df	Mean Square	F	P-value
Between Groups	3456.438	2	1728.219	0.68	0.513
Within Groups	94083.26	37	2542.791		
Total	97539.698	39			

Discussion

The relationship between stature and cortical bone in this population appeared to be stronger for females, which may be an indicator of their workload being greater than that of their male counterparts. Stature is related to muscle force used during physical activity, and research suggests that those of taller stature require more muscle force to move their bodies. This is theorized to be due to the need for more force to act upon joints to move when there is greater distance between the levers involved in an action (Murray and Stock 2020). This explains the trend in this sample of a positive association with stature and cortical bone area, as that same muscular force also increases the apposition of cortical bone (Agostini and Ross 2011, 339).

One possible explanation for the lack of a statistical correlation between stature and femoral cortical bone area is the sample size. A relatively small number of individuals can yield insignificant results due to a lack of sufficient data points. Alternatively, this may also be due to the average body size of the sample. The people of Tipu were all of a similarly small stature and relative robusticity (Noldner 2013), so the impact stature would have on cortical bone area would likely be more difficult to elucidate. However, the trend was on par with expectations, especially in the female portion of the sample, suggesting that the length of long bones may have worked in tandem with the force exerted upon them to produce cortical bone.

Pilastric Index

The pilastric index is the ratio between the mediolateral and anteroposterior diameters at midshaft (Holtby 1918); therefore, a greater index indicates proportionally greater development of the linea aspera than the mediolateral plane of the diaphysis. This dimension was expected to show a strong positive correlation with cortical bone area, because both variables are acted upon by the same forces. If assuming that activities which increase cortical bone density also put mechanical load on the axes of the femur, there should have been a strong relationship between them.

Females

After being split into three groups of equal range based on their pilastric indices, females were first tested to see if this relationship existed in the population as expected (Table 7). No significant correlation was indicated in this test for females in the sample, meaning that there was no relationship between their cortical bone area and the ratio of development along the two perpendicular planes of the femur. The pattern observed in this test was actually the opposite of what was expected from the sample, as the cortical bone area trended down as the pilastric index increases.

Table 7 *Correlation between pilastric index and cortical bone area, females*

Groups	N	Sum	Average	Variance	
83-93	12	4165.689	347.141	2397.581	
93.1-103	11	3729.495	339.045	1901.318	
103.1-113	7	2329.898	332.843	1750.147	
Source of Variation	Sum of Squares	df	Mean Square	F	P-value
Between Groups	959.547	2	479.774	0.232	0.795
Within Groups	55887.453	27	2069.906		
Total	56847	29			

Males

An additional correlation for the male group was calculated comparing the pilastric index with the cortical bone area (Table 8). Of the males in this study, the only individuals who had indices that were considered to have definitive pilastry, defined as an index greater than 116 (Holtby 1918), were the three in the latter category. Even so, the data showed no significant relationship between the pilastric index and the volume of cortical bone in the femur. In fact, just as with the female group, the opposite of what was expected was observed here. The group with pilastry had the lowest mean cortical bone area, and the other two groups had virtually the same amount of cortical bone.

Table 8 *Correlation between pilastric index and cortical bone area, males*

Groups	N	Sum	Average	Variance	
90-103	18	7574.478	420.804	3283.889	
103.1-116	19	7993.229	420.696	1894.461	
116.1-127	3	1187.711	395.904	2950.106	
Source of Variation	Sum of Squares	df	Mean Square	F	P-value
Between Groups	1713.067	2	856.533	0.331	0.721
Within Groups	95826.631	37	2589.909		
Total	97539.698	39			

Discussion

The results appeared to show that pilastric index and cortical bone area moved in opposite directions for the individuals in this sample. While this was not the expected result, it may be understood by taking a look at what each variable was intended to measure. Cortical bone exists in the endosteal portion of the bone, while the pilastric index measures the ratio of the diaphyseal shape in terms of how its two main axes relate (Holtby 1918). The diaphyseal shape is not necessarily directly correlated with the amount of cortical bone inside. The pilastric index would be more directly linked to development on the periosteal aspect of the bone rather than the appositional growth inside the medullary cavity. Even so, entheses, which develop on the outside surface of long bones, can develop without affecting the overall shape of the diaphysis (Noldner and Edgar 2013).

One possibility is that the overall shape of the diaphyses in this sample were all too similar for the pilastric index to vary greatly enough to be correlate with any other variable. The lack of sexual dimorphism in cross-sectional shape observed in the Tipu population could certainly account for such a result (Noldner 2013). There also exists a possibility that paying tribute to the Spanish would have homogenized the population’s workload to a point that any distortion of diaphyseal shape due to mechanical force was similar among all individuals (Graham 2011). However, since the results were the opposite of what was expected and the relationship between cortical bone and pilastric index trends negative, other explanations could be explored. Pilastry could be the default diaphyseal shape in the femora of this population, and the same physical labor that built up cortical bone may have distorted this shape to make the indices lower for those individuals. Results from the study of pre-contact Maya do not appear to exhibit this same lack of relative anteroposterior robusticity. While the pilastric index among Maya populations appeared to have a secular downward trend, there have been clear indicators of load bearing in the anteroposterior axis for the pre-Hispanic Maya (Wanner et al. 2007). No definitive cause can be suggested to account for the lack of correlation between pilastric index and cortical bone area in Tipu without further investigation into this matter.

Burial Location

Burial practice is one of the primary indicators of cultural change in Colonial Maya society (Graham et al. 2013). At Tipu, the Spanish influence is clear in the way the burials are aligned laying supine with their heads facing west in and around the church, in contrast with earlier Maya traditions which often included seated or flexed burials inside multiple different structures (Graham et al. 2013). It has been proposed that higher status individuals at Tipu were buried closer to the altar in accordance with European burial convention (Cohen et al. 1989; Jacobi 2000; Noldner 2013; Saul 1982). This is based on the fact that the cemetery at Tipu clearly adheres to Spanish Catholic tradition (Graham et al. 2013); therefore, status would be expected to be distinguished in the cemetery through this practice.

Cortical bone density may help explore whether burial practices affirm this proposition, because it is evidenced that cortical bone density increases with workload (Bridges 1989) and therefore would be greater in lower-status individuals who performed more manual labor. In order to test the veracity of the assumption about status at Tipu, I tested whether there was a significant relationship between burial location and cortical bone area.

Females

For females, this hypothesis was tested to determine if there is a significant difference in cortical bone area values between those buried inside the church and those outside the church (Table 9). The analysis indicated no significant correlation between these variables. However, the mean cortical area trended in the expected direction if those buried inside the church are assumed to be of higher status than those outside.

Table 9 *Cortical bone area correlation for inside/ outside, females*

Groups	N	Sum	Average	Variance	
Inside	16	5366.796	335.425	2499.306	
Outside	14	4858.286	347.02	1411.803	
Source of Variation	Sum of Squares	df	Mean Square	F	P-value
Between Groups	1003.966	1	1003.966	0.503	0.484
Within Groups	55843.034	28	1994.394		
Total	56847	29			

Though the initial analysis of burial location rendered no significant difference in cortical bone area, the sample was further broken down by dividing the group buried inside of the church into front and back, with the latter being the presumed high-status individuals. These two groups were then tested along with the outside burials to see if there was a correlation between these locations of burial and the cortical bone area (Table 10). This test had a slightly lower p-value than the previous test, but still did not qualify as statistically significant. However, it did reveal that those inside the front of the church are the group with the lowest degree of cortical bone development, which supports the prediction that this group may have had the lowest workload.

Table 10 *Cortical bone area correlation for all burial locations, females*

Groups	N	Sum	Average	Variance	
Inside back	8	2778.961	347.37	2105.112	
Inside front	8	2587.835	323.479	2924.392	
Outside	14	4858.286	347.02	1411.803	
Source of Variation	Sum of Squares	df	Mean Square	F	P-value
Between Groups	3287.038	2	1643.519	0.829	0.447
Within Groups	53559.962	27	1983.702		
Total	56847	29			

The last correlation assessed for the female group was how stature relates to burial location (Table 11). The burial locations used for this test were also outside, inside back, and inside front. These variables were tested against one another to see if, rather than cortical bone area, stature might be an indicator of a burial plan at the site. However, though this relationship appeared stronger than most of the other variables examined, there was no significant correlation between these two factors. This test aligned somewhat with the comparison of cortical bone area and burial location. However, in that test, the outside and inside back group had greater cortical bone development. With stature, the tallest individuals were in the outside and inside front groups. The individuals buried in the front of the church may have exhibited a greater stature due to their status due to a potential preferential access to resources.

Table 11 *Correlation between stature and burial location, females*

Groups	N	Sum	Average	Variance	
Inside back	8	1156.2	144.525	12.251	
Inside front	8	1181.9	147.738	23.426	
Outside	14	2070.2	147.871	12.508	
Source of Variation	Sum of Squares	df	Mean Square	F	P-value
Between Groups	63.891	2	31.946	2.092	0.143
Within Groups	412.342	27	15.272		
Total	476.234	29			

Males

The male portion of the sample was subjected to the same series of statistical analyses as the female group. Initially, the cortical bone area inside versus outside of the church was evaluated (Table 12). This correlation demonstrated no significance, although the p-value for this test was much lower than that of females, meaning that the relationship was stronger for the males in the sample. Unlike what was observed with the females, the means for these groups demonstrated an opposite trend of what would be expected, because those inside the church had much more cortical bone area than those outside, who were assumed to have a greater burden of manual labor.

Table 12 *Cortical bone area correlation for inside/ outside, males*

Groups	N	Sum	Average	Variance	
Inside	24	10244.145	426.839	2804.909	
Outside	16	6511.273	406.955	1948.727	
Source of Variation	Sum of Squares	df	Mean Square	F	P-value
Between Groups	3795.895	1	3795.895	1.539	0.222
Within Groups	93743.803	38	2466.942		
Total	97539.698	39			

The next test involved dividing the inside burial group into back and front of the church and testing for a correlation between the three burial locations and cortical bone area (Table 13). Like the previous test, this one did not exhibit a significant correlation. Also, unlike with the female group, this p-value for this test was much greater than for the test only divided into inside and outside groups. Of those buried inside the church, the observed cortical bone area was as expected, with the front group showing a lesser degree of development in that area. However, the outside group defied what would be expected if those individuals are of lower status and had a greater manual workload.

Table 13 *Cortical bone area correlation for all burial locations, males*

Groups	N	Sum	Average	Variance	
Inside back	16	6854.374	428.398	3269.784	
Inside front	8	3389.771	423.721	2192.782	
Outside	16	6511.273	406.955	1948.727	
Source of Variation	Sum of Squares	df	Mean Square	F	P-value
Between Groups	3912.558	2	1956.279	0.773	0.469
Within Groups	93627.14	37	2530.463		
Total	97539.698	39			

The final analysis performed on the male portion of the sample was a comparison between the burial location and stature (Table 14). The three burial locations of outside, inside back, and inside front from previous comparisons were used here as well. This test resulted in a very high p-value, meaning that the comparison of these variables could not be construed to approach any sort of significance and they therefore had no meaningful relationship to one another. Additionally, while the outside group was slightly taller, the mean values for each of the groups were very close to one another, indicating that all males in the population had similar stature distribution regardless of burial location.

Table 14 *Correlation between stature and burial location, males*

Groups	N	Sum	Average	Variance	
Inside back	16	2532.8	158.3	15.937	
Inside front	8	1271.2	158.9	35.183	
Outside	16	2547	159.188	16.848	
Source of Variation	Sum of Squares	df	Mean Square	F	P-value
Between Groups	6.457	2	3.229	0.162	0.851
Within Groups	738.058	37	19.948		
Total	744.515	39			

Discussion

When stature and burial location were compared, the results showed no correlation for either males or females. The variance in stature among groups of different burial locations was very little, which is in line with previous research indicating that the individuals at Tipu were all generally of a similar body size to one another (Noldner 2013). The lack of any discernible trend for stature and burial location is a likely indicator of nutritional availability across the site. Because no groups in the population appeared to have a notable difference in stature from the rest, there was likely no preferential access to resources at the site that would have affected stature. The fact that no agricultural intensification with Spanish occupation at the site was indicated in prior research seems to support the idea that individuals at Tipu would have likely all had their nutritional needs met to the same degree (Graham et al. 1989, 1255). When considered along with the results of the comparison between cortical bone area and burial location, this data also leads to the conclusion that there were no indications of a status-based burial plan at Tipu.

Cortical Bone Maintenance at Tipu

The primary hypothesis of this research is disproved by the fact that burial location and cortical bone area show neither a correlation nor a trend in the expected direction. The context of the population may help to explain this result. The people of Tipu, in addition to likely having similar occupational labor demands, also showed consistency in their health markers. The population was generally healthy, with few pathologies and little evidence of endemic infectious disease (Cohen et al. 1997; Graham et al. 1989; Jacobi 2000). There were also no large differences in stature to imply a great differential in access to resources as children (Cohen et al. 1997). This could be assumed because appositional bone growth and epiphyseal growth both rely on nutritional stability to some degree (Seeman 2001). Previous research discovered some clusters of individuals in the cemetery that appear to be more robust in their upper arm musculature (Noldner 2013). For females, a small group in the northern outside portion of the cemetery had significantly more developed forearm pronation indicators. Males inside the center portion of the church appeared to have greater pectoralis development. However, there were no other strong indicators in Noldner's (2013) research, so the small number of individuals in the burial clusters and lack of consistent results across the site indicate that this may have been coincidental. Additionally, the similarity between Tipu burial clusters and known elites from pre-contact populations varied based on the specific musculature being compared. There were also no significant differences observed in the lower limbs, and all results suffer from a lack of statistical power given the small sample sizes for each cluster (Noldner 2013). Combined with the results of this research, the health indicators in the Tipu population do not appear to suggest that any particular individuals were favored in terms of their access to resources or burial location.

At pre-colonial Maya sites like Copán and Altar de Sacrificios, the primary evidence of elites in a cemetery context is discerned through grave goods and burial treatment rather than biological factors (Ballinger 1999). Tipu exhibited none of these traditional Maya signifiers of status in its cemetery, with all burials being treated more in the Catholic tradition, or at least appearing to do so because of the great cultural shift brought by colonialism (Cohen et al. 1997; Graham et al. 2013). This may be due to the Spanish presence precluding the indigenous Maya from obtaining high status in their society (Ballinger 1999). One possible explanation is that resources were stretched thin due to the demand of tribute by the Spanish, leaving no room for prestige to be cultivated and imposing a heavy labor cost for basic survival in Tipu (Graham 2011). Additionally, the health markers at the site seem to indicate no discernible burial groups in which the individuals were more or less prone to disease and illness due to nutritional deficit, implying that access to resources was equitable, and therefore not indicating the presence of elites (Jacobi 2000; Noldner 2013).

Another theory concerning status for the colonial Maya relates to the Spanish influence on ideas of what constitutes status in the Maya world. It has been suggested that Spanish literacy, as taught by the Catholic friars, was the primary indicator of status in Colonial Yucatán (Chuchiak 2010). This measurement of status cannot be evaluated biologically, so it would not be evident in any analysis of the remains. Additionally, the lack of Spanish oversight at Tipu may have meant that no one living there would have been literate in Spanish and therefore would not qualify for elite status (Graham 2011). In this way, the Spanish may have imposed standards that oppressed Maya culture to the point that it led them to become more egalitarian than their Classic and Postclassic counterparts.

Though the religious influence of Catholicism in Tipu is undeniable, it is also arguable that the change in burial practices is a result of a culmination of cultural change surrounding death. The warfare, disease, and poverty brought to the Maya by the Spanish changed their perception of how and why death occurs (Graham et al. 2013). The cultural climate brought by Spanish occupation also allowed for the Maya to appropriate customs and incorporate these with their existing traditions. Colonial Maya funerary practices were not only rapidly changing, but they were a hybridization of cultures (Masson et al. 2021). Additionally, Tipu was known for its rebellion against Spanish rule and may have simply chosen to shirk the burial traditions and cultural pressures that would have indicated status in the Colonial world (Graham 2011). These and potentially other factors could cause the burial practices at Tipu to have shifted many times over the course of the cemetery's use.

There are other potential reasons why this research did not indicate any elite burials at the site. Sample size is an important consideration, and the lack of a large number of suitable adult femora available for analysis may have simply caused the results to not be indicative of trends in the entire population given that only 70 of the individuals were analyzed here. The subdivision of the sample into smaller groupings based on the variables tested also limited the scope of possible inferences. Some simpler explanations may also account for a lack of evidence for any status differential at the site. It is possible that little foresight or oversight was used in the burial plan, and any elites that were present may have just been placed among the other individuals without special treatment. Timing may also play a part in the seemingly random apportionment of cemetery space. Certain cemetery locations may have been used for all burials until space ran out and another location was then utilized. If this is the case, it is most likely that the inside of the church was the primary burial location, and the outside was used once space was no longer available inside. If certain positions in the cemetery were indeed used at different times rather than contemporaneously for individuals of different status, individuals of all statuses would be mixed throughout the site. However, Musselwhite (2015) used fluorine analysis to test this possibility and found that all areas of burial were used contemporaneously, which indicates that there should be an explanation for differential places of burial for individuals who were interred around the same time. Ultimately, all that is known about status at Tipu as of now is that no elites are evident in terms of burial treatment or biological differences. More exploration is necessary to know if elites even existed at the site, but we now know that cortical bone area is not associated with burial location.

When considering the results all together, it is clear that there are notable trends in how cortical bone area is distributed among individuals at the site. However, the only significant factor that could demonstrably be distinguished through femoral cortical bone was sex. Females in the Tipu population showed a great deal less area than males, who may likely either traveled more frequently or had inherently greater robusticity in their legs. Sex also appeared to be a factor when age was considered as well, with females showing a slight decrease in bone density with age, with the opposite being true of males. Though the differences were very slight among age groups, they would suggest that the older group of females in this study may have begun the progressive bone loss associated with menopause.

The trend in stature appeared the same for males and females, with those who were of taller stature in both groups having a slightly greater degree of femoral cortical bone area. While again not statistically significant, this could potentially indicate a minor correlation between the two factors. Likewise, males and females displayed similar trends to one another when cortical bone area was compared with pilastric index. However, the results of this comparison were the opposite of what was expected, with a slight negative relationship between the two variables. Because this is not a significant result, however, any number of explanations could be considered for why this is so, including that the data simply does not represent a demonstrable trend given the sample size.

Finally, the results for how cortical bone is distributed at different locations in the cemetery indicates a lack of a status-related burial plan, at least as can be determined through skeletal evidence. This could mean that an alternative strategy was used at the site in terms of the deposition of remains or that the site did not include any elite individuals at all. When considered with the rest of the evidence discussed here, there is no apparent differentiator between individuals at Tipu which would indicate that their lifestyles differed significantly from one another in any way that would impact their femoral robusticity.

CHAPTER V – CONCLUSIONS

The Tipu population lived at a time of great cultural change due to Spanish colonialism, as evidenced in the burial practices performed at the site. The goal of this research was to determine whether cortical bone area in the femur can reveal activity patterns in the population. The femora of 70 Tipuan adults were examined for endosteal cortical bone area, which signifies a relative level of physical labor performed by an individual. This data was compared with demographics of the sample to see if age and sex were correlated to femoral density. Additionally, stature and pilastric index were analyzed to see if these factors related to cortical bone development. Finally, burial location was examined to observe how it corresponded with femoral robusticity to determine if the practice of status-based burial planning was part of the cultural change in Tipu's burial traditions brought on by Spanish occupation.

Of the variables tested for their relationship with cortical bone area, the only one studied here that displayed a correlation was sex. While expected trends in the cortical bone were observed in other factors, including a decrease with age and an increase with stature, no definitive links can be asserted due to a lack of statistical significance. Pilastric index appeared to indicate a slight trend of a negative relationship between cortical bone area, however, it was not as expected. Burial location was expected to reveal that those with lower cortical bone area, who would have performed less physical labor, would be distinguished in a high-status part of the cemetery. This analysis did not yield any consistent results for the male or female groups, and all of these comparisons failed to demonstrate acceptable correlations.

There are a few potential reasons for the lack of significance for most of the data analyzed here. Primarily, the sample size of only 70 individuals is quite small for research of this nature, especially when subdivided into groups for each variable. Though the remains from Tipu constitute a sizable population in a bioarchaeological context, having been limited to so few individuals made it quite difficult to assert that any data demonstrated factors about the entire population.

There are additional considerations when it comes to the accuracy of the methodology used here. Though the BoneJ software detected cortical bone area automatically, the images often had to be manipulated manually in order to be interpreted correctly by the program. The lack of precision when tracing borders by hand using a stylus was quite a struggle, and human error certainly affected the results. This is especially demonstrated by the fact that the images were each run through the process thrice, and most yielded slightly different results each time. While most showed similar numbers for all three, some individuals' numbers were significantly different. For example, one individual's cortical bone area measurements were 443, 428, and 414. Though an average was taken for the three figures for cortical bone area on each individual, the inconsistencies demonstrated a lack of accuracy with the image processing method. Standard error calculated for each individual fell between 0.9 and 17 percent, and each subsequent round of image processing appeared to decrease the value for cortical bone area for most individuals. Another potential source of error is the stature calculations for the individuals. The femora used for imaging were the same bone used to calculate stature for each individual. Because they were bisected, measuring them was challenging and could have yielded inaccurate results. Additionally, many of the femoral maximum length measurements had to be estimated due to a lack of epiphyseal preservation.

In future lines of research, it would be prudent to consider using other skeletal elements in addition to femora to elucidate a more nuanced idea of how workload was distributed at Tipu. The femur alone can only indicate a relative level of locomotion, whereas other long bones may be able to contribute better data in terms of differential labor patterns. The humerus is likely to yield the best results in terms of examining labor differentiation because the arms are used in a more task-specific way than the legs. Using one or more comparative collections could also help to better contextualize the data collected from Tipu. Knowing where other Maya populations, both pre- and post-Columbian, stand in terms of their cortical bone density would help to clarify the positionality of this data as a part of the indigenous Mesoamerican story.

While the results here did not validate the hypotheses as expected, they did clarify some speculations about life at Tipu. The lack of strong correlations indicated that elites were likely either not present or not that much different from commoners in their day-to-day activities. This was in contrast with what is observed in some pre-Columbian Maya settings, indicating that the Spanish presence did have an impact the labor performed at the site. However, some potential problems with the accuracy of the methodology may have caused these results to be ineffective at determining more about the Tipu population. Future research in this realm using more data points and more accurate methods can help to discover more about this population and how their lives were impacted by Spanish occupation.

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